

EXTERNAL DEFIBRILLATOR WITH SHOCK ACTIVATED BY CESSATION OF PRECARDIAL COMPRESSIONS

5 The present invention relates to devices used in electrical therapy and, in particular,
to a defibrillator for delivering artifact-compensated defibrillation pulses while cardio-
pulmonary resuscitation (CPR) is being performed on a patient.

Medical equipment manufacturers have developed Automated Electronic
Defibrillators (AEDs) to provide early defibrillation. AEDs deliver a high-amplitude
current pulse, waveform, or shock to the heart in order to restore the patient's heart rhythm
10 to a normal level. For example, FIG. 1 depicts the conventional AED 6 being applied to a
cardiac arrest victim 2 by a rescuer 4. As shown in FIG. 1, a pair of defibrillation
electrodes 8 is placed on anterior-anterior (AA) positions on the victim's torso for
delivering the shocks. At the same time, it is also necessary to perform a cardio-
pulmonary resuscitation (CPR) on the patient while delivering the defibrillation shocks in
15 order to revive the victim from the cardiac arrest.

In treating victims of cardiac arrest with a defibrillator, it is important that the
treatment be performed very rapidly as their chances of surviving the cardiac arrest
decrease drastically over time following the cardiac arrest. Thus, a quick response to
cardiac arrest in administering a defibrillation shock after performing the CPR precordial
20 compressions at the rescue scene is critical. In addition to deploying a defibrillation shock
rapidly as needed to improve the resuscitation benefit, measuring accurate signals in the
presence of other artifact signals, such as the movement of the victim during the CPR
operation, is vital when making a correct decision with respect to a patient's treatment or,
for devices that use algorithms to make decisions.

25 With regards to the above paragraph, there are two time intervals that are of
importance, only one of which is addressed by this invention. The chance of survival
decreases rapidly following the loss of circulation. Consequently the time from the
beginning of the arrest until the first defibrillation shock is important. This interval is
important whether or not CPR is performed, but is not addressed by this particular
30 invention. When CPR is performed, some level of circulation is restored artificially, which
can improve the chances of survival. When CPR is discontinued to allow the AED to
analyze the heart rhythm (via the ECG), circulation is once again stopped. A long interval

between discontinuation of CPR and shock delivery will decrease the chance of survival. It is this second interval that is addressed by this invention.

Therefore, the present invention provides an improved defibrillator that is easy to use and that enables a minimally trained user to easily, rapidly, and effectively deploy the defibrillator to treat the patient, while reducing the time interval between precordial compressions and delivery of a defibrillation shock.

The present invention is directed to a method and system for quickly and accurately applying the defibrillating shock to a victim of sudden cardiac arrest following delivery of CPR precordial compressions.

A more complete understanding of the method and apparatus of the present invention is available by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 is an illustration of a defibrillator being applied to a patient under cardiac arrest according to an embodiment of the present invention;

FIG. 2 depicts a representative hardware of the defibrillator illustrated in FIG. 1 according to an embodiment of the present invention;

FIG. 3 is a diagram of the hardware configured to deliver an artifact-compensated defibrillation shock according to an embodiment of the present invention; and,

FIG. 4 is a flow chart illustrating the operation steps of the defibrillation system in accordance with the present invention.

In the following description, for purposes of explanation rather than limitation, specific details are set forth such as the particular architecture, interfaces, techniques, etc., in order to provide a thorough understanding of the present invention. For purposes of simplicity and clarity, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

In the prior art system, portable automated external defibrillators do not consider the mechanical disturbance of the patient as an inhibitor/enable of shock delivery. In particular, the mechanical movement of the patient's chest is not compensated during the delivery of electrical therapy, thus producing a corrupted signal, which is measured by the defibrillator. In addition, other artifacts that corrupt the signals, including mechanical disturbances of sensors, electromagnetic interference, etc., are used to trigger the treatable

shocks, thus resulting in inaccurate reading when delivering the defibrillation shock. Furthermore, prior art defibrillators have presented a shock hazard to the rescuer as the defibrillators are incapable of detecting whether the rescuer was in physical contact with the patient. One way to address this problem in the prior is to provide a “no touch” interval period prior to delivering the therapy shocks. However, this delay is undesirable as it delays the interval between the CPR precordial compressions and the delivery of defibrillation shock, thus preventing a quick response in administering a defibrillation shock which is vital in increasing the chance of surviving the cardiac arrest.

The above paragraph is not an accurate description of the prior art. First, let’s distinguish between motion detection and artifact detection. Motion detection determines, via means of an external transducer or patient dependent parameter (e.g. transthoracic impedance), that the patient is being physically disturbed. It does not compare the disturbance signal to the patient’s ECG to determine whether the motion has been manifested as corruption of the ECG signal. Artifact detection acquires a disturbance signal, which can be patient motion or any other possible source of ECG disturbance (e.g. electromagnetic), and compares it to the patient’s ECG, e.g. by cross-correlation, in order to determine if the disturbance has manifested itself as corruption of the ECG. Such a corruption would make analysis of the ECG for shock advisory purposes unreliable, since the ECG is known to contain signals that are not of cardiac origin.

A typical AED therapy sequence following CPR is as follows:

1. Instruct rescuer “stop CPR”, or “do not touch the patient.”
2. Allow a short interval (e.g. 3 seconds or less) for the rescuer to discontinue CPR.
3. Begin acquiring ECG & disturbance signal for analysis.
4. Analyze an interval (e.g. 4.5 seconds) of ECG and disturbance signal. If motion is detected, repeat step 4, otherwise proceed to step 5.
5. If ECG analysis indicates VF or VT, begin charging therapy capacitor. At this point, the shock button is not armed, i.e. pressing it will have no effect.
6. Once capacitor is fully charged, arm the shock button and instruct the rescuer to press it.

The ForeRunner and FR2 (Philips) AED therapy sequence following CPR is as follows:

1. Instruct rescuer “do not touch the patient.” Begin charging the therapy capacitor to an intermediate level (Philips patented precharge).

2. Allow a short interval (e.g. 3 seconds or less) for the rescuer to discontinue CPR.
 3. Begin acquiring ECG & disturbance signal for analysis.
 4. Analyze an interval (e.g. 4.5 seconds) of ECG and disturbance signal. If artifact is detected, repeat step 4, otherwise proceed to step 5.
 5. If ECG analysis indicates VF or VT, finish charging therapy capacitor. At this point, the shock button is not armed, i.e. pressing it will have no effect.
 6. Once capacitor is fully charged, arm the shock button and instruct the rescuer to press it.
1. The therapy sequence that we wish to protect is as follows: At a predetermined interval prior to the end of CPR, begin charging the therapy capacitor to an intermediate level (Philips patented precharge).
 2. Instruct rescuer "stop CPR", or "do not touch the patient". Initiate final charging of therapy capacitor.
 3. Allow a short interval (e.g. 3 seconds or less) for the rescuer to discontinue CPR.
 4. Begin acquiring ECG & disturbance signal for analysis.
 5. Analyze an interval (e.g. 4.5 seconds) of ECG and disturbance signal. If artifact and/or motion is detected, repeat step 5, otherwise proceed to step 6.
 6. If ECG analysis indicates VF or VT, arm the shock button as soon as full charge is achieved (which may be immediately) and instruct the rescuer to press it. Otherwise, instruct "no shock advised."

An alternative embodiment is as follows:

1. Instruct rescuer "stop CPR", or "do not touch the patient". Immediately begin charging the therapy capacitor to full charge.
2. Allow a short interval (e.g. 3 seconds or less) for the rescuer to discontinue CPR.
3. Begin acquiring ECG & disturbance signal for analysis.
4. Analyze an interval (e.g. 4.5 seconds) of ECG and disturbance signal. If artifact and/or motion is detected, repeat step 4, otherwise proceed to step 5.
5. If ECG analysis indicates VF or VT, arm the shock button as soon as full charge is achieved (which may be immediately) and instruct the rescuer to press it. Otherwise, instruct "no shock advised."

In otherwords, the ideas that we wish to protect are:

- Initiate full charge of the therapy capacitor prior to having knowledge as to whether we will recommend a shock or not. This may, or may not, be proceeded by pre-charging the capacitor.
- 5 • Acquiring ECG and disturbance data during the capacitor charging operation (there is Philips prior art for this; both ForeRunner and FR2).
- If ECG analysis indicates a heart rhythm deemed to be “shockable” (i.e. would benefit from electrical shock therapy), and a disturbance criteria is met, arm the defibrillator shock button immediately (with little or no delay to complete capacitor charging).
- 10 Alternatively, the shock may be delivered automatically.
- The disturbance criteria may be any of the following:
- The absence of disturbance (e.g. motion), as determined solely from one or more disturbance signals
- The absence of artifact, as determined by cross-correlation (or similar operation) of the
- 15 ECG and one or more disturbance signals (Philips patented)
- The absence of disturbance AND artifact.

In contrast, the present invention provides a defibrillation system in which the delivery of electrical therapy shocks is triggered by a combination of the detection of a treatable arrhythmia via an ECG analysis and a detection of the cessation or absence of

20 CPR precordial compressions. Moreover, the inventive defibrillation system reduces the time interval between precordial compressions and a subsequent delivery of the defibrillation shock to less than 5 seconds. Furthermore, the inventive system detects the corruption of signals using a variable artifact analysis to determine an appropriate output level of the defibrillation shocks.

25 Figure 2 is a simplified block diagram of the defibrillator in accordance with the embodiment of the present invention. The defibrillator 20 may include a mechanical disturbance detector 10, an electrocardiogram (ECG) front end 32, a timer 34, a defibrillation activation/deactivation button 36, a HV switch 38, a processor 40, a display 42, an energy storage capacitor network 44, a voltage charger 46, and a battery 48. It

30 should be noted that any number of commercially or publicly available defibrillator

configured to generate a defibrillation shock can be utilized in various implementations in accordance with the preferred embodiment of the present invention.

As shown in FIG. 2, the mechanical disturbance detector 10 is connected to a sensor 12 that is placed on the patient to detect the movement of the patient during the delivery of CPR precordial compressions. The movement of the patient that may potentially corrupt the accurate assessment of the signal of interest is detected and forwarded to the processor 40. Similarly, the ECG front end 32 is connected to the electrodes 22 and 24 that are placed on the patient to amplify, filter, and digitize (using an analog to a digital converter) an electrical ECG signal generated by the patient's heart. The detected ECG samples are received by the processor 40, which runs a shock advisory algorithm for detecting VF or other shockable rhythm requiring treatment by the defibrillation shock. The ECG front end 32 is also capable of measuring the patient impedance across the electrodes 22 and 24 using a low-level test signal that is a non-therapeutic pulse to measure the voltage drop across the electrodes 22 and 24. The detected patient impedance is analyzed by the processor 40 to determine the appropriate energy level desired to be delivered to the patient. In an alternate embodiment, the function of the mechanical disturbance detector 10 and the ECG front end 32 can be merged as one component, such that one of the electrode connected to the ECG front end 32 may serve as a sensor for detecting the movement of the patient.

The HV switch 38 is configured to sequentially deliver the defibrillation pulse across the pair of electrodes 22 and 24 to the patient in the desired polarity and duration. It should be noted that the HV switch 38 could be adapted to deliver a single polarity (monophasic), both negative and positive polarities (biphasic) or multiple negative and positive polarities (multiphasic) in the preferred embodiment. The timer 34 is connected to the processor 40 for providing a defibrillation pulse interval or duration when delivering the defibrillation pulse across the electrode pair 22 and 24. The activation/deactivation button 36 is connected to the processor 40 to enable the user to activate/deactivate the delivery of a defibrillation pulse across the electrodes 22 and 24 when the VF or other shockable rhythm is detected. Note that the activation/deactivation button 36 can function in both AED and manual modes in the preferred embodiment. The display 42, connected to the processor 40, is preferably a liquid crystal display (LCD) and provides audio and visible feedback to the user. The battery 48 provides power for the defibrillator 20 and in

particular for the voltage charger 46, which charges the capacitors in the energy-storage capacitor network 44. The energy-storage capacitor network 44 includes a plurality of capacitors and resistors that are arranged in series or parallel arrangement, or a combination of series and parallel arrangement to supply a plurality of voltage-level outputs across the electrodes 22 and 24. It will be apparent to those skilled in the art that a variety of RC arrangements can be implemented to generate different voltage levels. In an alternate embodiment, the function of the energy-storage capacitor network 44 can be performed by functionally equivalent circuits, such as a digital-processor circuit or an application-specific integrated circuit (ASIC).

10 In operation, the electrodes 22 and 24 connected to the ECG front end 32 is placed on a patient for obtaining the patient impedance. The processor 40 uses the information received from the ECG front end 32 to control the shape of the waveform of the defibrillation pulse delivered to the patient in real time. The defibrillation pulse delivered to the patient may be a fixed level, or a number of defibrillation pulses at different energy levels. This can be achieved by selecting the appropriate voltage level of the energy-storage capacitor network 44 from the set of configurations to deliver the desired impedance-compensated defibrillation pulse to the patient.

When a rescuer performs chest compressions as part of doing CPR on the patient, the resulting chest movement tends to disturb the electrodes placed on the chest area. As such, the sensor 12, such as an accelerometer that is connected to the mechanical disturbance detector 10 is also placed on the patient for detecting the patient's movement in response to the precordial compressions. This is undesirable as the movement of the electrodes on the chest skin area generates interfering electrical noise or artifacts, which corrupts the ECG signal. As discussed in detail later, the artifact in the ECG signal caused by mechanical disturbances of sensors, electromagnetic interference, other environmental conditions, or artifact caused by movement due to the cardio-pulmonary resuscitation (CPR) operation are reduced, thereby enhancing the analysis of the ECG signal during a CPR operation. The ability to analyze the ECG accurately and rapidly during the CPR operation reduces the time that the defibrillation shocks must be delivered to the patient after the discontinuation of the mechanical disturbance which increases the chances of a successful rescue attempt. The inventive system 20 is also provided with the display 42 for

visually indicating the shock annunciation, or may be equipped with a speaker (not shown) for providing audible announcement just prior to delivering the defibrillation shocks.

Note that during the rescue attempt, if renewed mechanical disturbance is detected, the defibrillation activation/deactivation 36 is provided for cancellation of the shock within
5 the brief delay interval prior to therapy deliver. Alternatively, the motion of new mechanical disturbance can be detected automatically and cause the cancellation of the defibrillation shock therapy.

Figure 3 is a detailed description of the components that enable a rapid analysis during mechanical disturbances, so that arrhythmia determination can be made using
10 artifact-free ECG following the cessation of mechanical disturbance. Note that detecting artifact can be performed in a variety of ways. For example, signal processing and correlation of processed signals in accordance with the present invention may include various embodiments described in U.S. Patent Application No. 6,287,328, filed by the applicant and issued on September 11, 2001, entitled "Multivariable Artifact Assessment,"
15 the teachings of which are incorporated herein by reference.

Briefly, an input signal indicative of patient movement is received via the sensor 12 and provided to the measurement circuit 10. The signal is then sent to a signal processor 52 and forwarded to a correlator 54, and the correlated signal is transmitted to the processor 40. The processor 40 then evaluates the signals to produce an output 102.
20 As will be appreciated by those skilled in the art, an appropriate signal processing includes, for example, band-pass filters, Fourier transforms, wavelet transforms, and joint time-frequency spectrograms. In addition, the method for correlating the data can be any correlation method known in the art. For example, correlation methods include specific and general cross-correlation techniques, which include known mathematical functions as
25 well as any process that effectively correlates the data. Specific implementations include, but are not limited to, finite sampled or continuous estimates of cross-covariance and cross-correlation, both biased and unbiased. Alternatively, correlation may perform similarity comparisons between any multiple signals.

Meanwhile, an input signal indicative of the patient impedance is received across
30 the electrodes 22 and 24 and transmitted to a differential-mode amplifier 56 and a common-mode amplifier 52 which amplify the signal prior to transmitting the signal to the signals processors. The resulting signals are then transmitted to their respective signal

processors 58 and 64 which process the signals to emphasize particular features. The resulting processed signals are then transmitted to a correlator 60, which correlates the signals. At the same time, the input signal is transmitted to impedance detector 66, which provides a trans-electrode impedance signal to the signal processor 52. Signal processor 52 processes the signal from the impedance detector 68 to emphasize particular features of the signal. The resulting processed signal is then transmitted to a correlator 72, which correlates the signal processor 70 with the processed signal from the differential amplifier 58. Once the signals have been correlated at their respective correlators 60, 72, the resulting signals are transmitted to the processor 40, which then further evaluates the results of the correlators 60 and 72 to provide an indication of the degree of corruption of the signal of interest. The processor 40 finally provides an output signal, which may be analyzed further as discussed with respect to FIG. 4 below.

Figure 4 is a flow chart illustrating the operation steps of delivering an artifact-compensated defibrillation shock while administering a CPR treatment according to the present invention. Initially, the inventive defibrillator 20 is deployed in step 100 by attaching the sensor 12 and the electrodes 22, 24 to the cardiac victim to analyze a patient input signal. The input signal due to potentially corrupted signal and/or the movement of the patient during a CPR operation is detected. Note that it is common to perform CPR precordial compressions on the victim in conjunction with the use of the defibrillator during rescue attempts. As such, in step 120, the system 20 determines whether a CPR operation has stopped using the input signal from the sensor 12 in step 120. If so, the electrodes 22 and 24 connected to the ECG front end 32 detect an input signal, i.e., ventricular fibrillation (VF) and the patient impedance is measured by measuring a low-level test signal or delivering a non-therapeutic signal in step 140.

Thereafter, the signal processing is implemented in order to emphasize a particular feature of the data in the input signal in step 160. Here, various implementations of processing, including known techniques such as filters, Fourier transforms, wavelet transforms, and joint time-frequency spectrograms, are employed. For example, the lower spectral portion of a Fourier transform of an ECG signal might be correlated with a similarly processed impedance signal in order to enhance the detection of an artifact resulting from a defibrillator operator performing CPR on a patient being monitored. Accordingly, the correlating step 160 performs the function of measuring similarities

between the processed cardiac signal and the processed corrupted signals.

The resulting comparisons are then analyzed to determine an indication of the amount of artifacts present within the potentially corrupted cardiac signal.

The result of the comparisons is processed by the processor 40 in order to
5 determine the level of the defibrillation shock, which may include a series of successive defibrillation shocks at a predetermined interval, to be delivered to the patient. The energy level may be determined by the operator manually, or it can be determined by automatically utilizing a common protocol known in the art. Here, the processor 40 also determines the polarity and duration of the defibrillation shock. After determining the
10 desired energy level output, the processor 40 sends a notification signal to the user in step 180 prior to delivering the defibrillation shock. At the same time, the processor 40 sends a signal to the HV switch 38 to actuate the switches to discharge the desired defibrillation shock to the patient. Alternatively, the processor 40 may notify the operator via the display 42 to press the shock button 36 to actuate manually the delivery of the
15 defibrillation shock to the patient. Finally, the defibrillation shock is discharged to the patient in step 200, then the patient's heart is monitored to determine whether a subsequent defibrillation shock is necessary. If so, the above steps may be repeated to deliver the subsequent defibrillation shock.

While the preferred embodiments of the present invention have been illustrated
20 and described, it will be understood by those skilled in the art that various changes and modifications may be made and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt to a particular situation and the teaching of the present invention without departing from the central scope. Therefore, it is intended that the
25 present invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out the present invention, but that the present invention include all embodiments falling within the scope of the appended claims.

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